

High-Temperature Characterization of Alumina Substrates and Folded Slot Antenna

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Abstract

The characterization of 99.6% polycrystalline alumina substrates and folded slot antennas is presented in this paper. Coplanar Waveguide (CPW) calibration standards were fabricated on 99.6% polycrystalline alumina substrates. Thru-Reflect-Line (TRL) calibrations were performed at temperatures of 25 to 400°C over a frequency range from 0.5 to 50 GHz. The effective dielectric constant of the alumina substrates was determined to be relatively constant at 5.4 from 25 to 200°C and then increased steadily to approximately 6 at 400°C. The loss of the CPW lines increased as temperature and frequency increased as well noting that the increase in loss is even more profound as both the temperature and frequency increased simultaneously.

A CPW fed folded slot antenna fabricated on the alumina substrates is also presented. The Return Loss (RL) of a CPW fed folded slot antenna exhibits a self impedance matching technique. The RL of the folded slot antenna at 25°C displays a resonance at 3.5 GHz and is approximately 16 dB in magnitude. At 300°C the resonance shifts down in frequency to approximately 3.3 GHz and has roughly the same magnitude. However the loss of the antenna response also increases at this elevated temperature.

This work is part of the initial stages of an effort at NASA Glenn research Center to develop wireless sensors for harsh environments. This work can reduce cost, space to house all the hard wired connections, and reduce the weight of the overall units such as aerospace engines and allow for the placement of the wireless sensors in the engine which are not possible with hard wired sensors.

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Introduction

The ability to use high temperature electronics in wireless sensing applications is of great interest. Wireless sensors that can be used in harsh environments to transmit critical data back to a diagnostic counterpart can alleviate hard wire connections and other electronics otherwise required to complete the data path. For example the ability to characterize *in-situ* combustion environments of aerospace engines via wireless sensors would reduce the weight and space required to position the wire as well as allowing the opportunity to position the sensors in areas of the engine that were previously not possible when only hard wire connection is available.

Antenna characterization at elevated temperatures is required for the development of wireless electronics that operate in harsh environments, such as in aircraft engines. This paper discusses the characterization of 99.6% polycrystalline Al₂O₃ (alumina) substrates from 25°C to 400°C over a frequency range from 0.5 GHz to 50 GHz. A coplanar waveguide (CPW) fed folded slot antenna fabricated on the alumina substrate is characterized over the temperature range.

Alumina Characterization

To characterize the properties of the alumina substrates at elevated temperatures, CPW *Thru-Reflect-Line* (TRL) calibration standards were developed [1]. The CPW standards have a center conductor width of 130 μm and slot widths of 60 μm consisting of chrome (Cr) and gold (Au) with thicknesses of 200Å and 1.5 μm, respectively. The thru line is 5000 μm long, the short is 2500 μm long, and 4 delay lines of 15000, 6000, 2950, 844 μm long, not including the 5000 μm length for the thru line, are used. The substrate is 99.6 % polycrystalline alumina with a thickness of 635μm. The calibration was performed using Multical calibration software by NIST [2] and the HP 8510 C VNA at 25, 50, 100, 150, 200, 250, 300, 350, and 400°C. To heat the calibration standards on the alumina substrates, a special probe station with modified ground-signal-ground (GSG) probes was constructed [3]. For each temperature, Multical calculated the effective permittivity and attenuation of the CPW line. Figure 1a illustrates the effective dielectric constant vs. temperature at 5 and 10 GHz. The effective dielectric constant gradually increases from 5.4 to 6, which is an increase of approximately 10%, as the temperature rises from room temperature (25°C) to 400°C.

The attenuation vs. temperature at 10 GHz and 20 GHz is shown in Figure 1b. The loss is approximately 0.5 dB/cm until the temperature reaches 200°C, after which it begins to rise steadily as the temperature increases to 400°C. At 400°C, the loss is 3 and 3.5 dB/cm at 10 and 20 GHz, respectively. Figure 2 shows the attenuation of the CPW transmission lines over a frequency band from 0.5 to 50 GHz at every temperature from 25 to 400°C. The loss increases as the frequency increase from 0.5 to 50 GHz. This phenomenon increases more so as the temperature increases as well.

Antenna Design and Characterization

The folded slot antenna was fabricated on the same substrate, and the metal conductor is the same as the CPW calibration standards (Cr/Au: 200 Å /1.5μm). The folded slot antenna exhibits a self impedance matching technique which matches the input impedance of the antenna to the 50 Ω characteristic impedance of the CPW feed line [4, 5]. The folded slot antenna is shown in Figures 3a and 3b. The return loss (RL) of the antenna was measured at 25 and 300°C and is shown in Figure 4. The RL was measured using the special probe station and modified GSG probes just as with the CPW TRL calibration standards. The return loss at 25°C has a resonance at 3.5 GHz and is approximately 16 dB in magnitude. At 300°C the resonance slightly shifts down in frequency to approximately 3.3 GHz and maintains roughly the same magnitude. This can be attributed to the increase in the effective dielectric constant as the temperature increases. Also the RL of the antenna definitely suffers from an increase in attenuation which is consistent with Figures 2 and 3.

Conclusion

The characterization of 99.6% polycrystalline alumina substrates and folded slot antennas has been presented. TRL calibrations were performed at temperatures of 25 to 400°C over a frequency range from 0.5 to 50 GHz. The effective dielectric constant of the CPW on alumina substrates was determined to be relatively constant at 5.4 from 25 to 200°C and then increased steadily to approximately 6 at 400°C. The loss of the CPW lines increased as temperature and frequency increased as well noting that the increase in loss is even more profound as both the temperature and frequency increased simultaneously.

The RL of a CPW fed folded slot antenna that exhibit a self impedance matching technique has been presented. The RL of the folded slot antenna at 25°C displays a resonance at 3.5 GHz and is approximately 16 dB in magnitude. At 300°C the resonance shifts down in frequency to approximately 3.3 dB and has roughly the same magnitude. However the loss of the antenna response also increases at this elevated temperature.

This work is part of the initial stages of an effort at NASA Glenn research Center to develop wireless sensors for harsh environments. This work can reduce cost,

space to house all the hard wired connections, and reduce the weight of the overall units such as aerospace engines and allow for the placement of the wireless sensors in the engine which are not possible with hard wired sensors.

Acknowledgments

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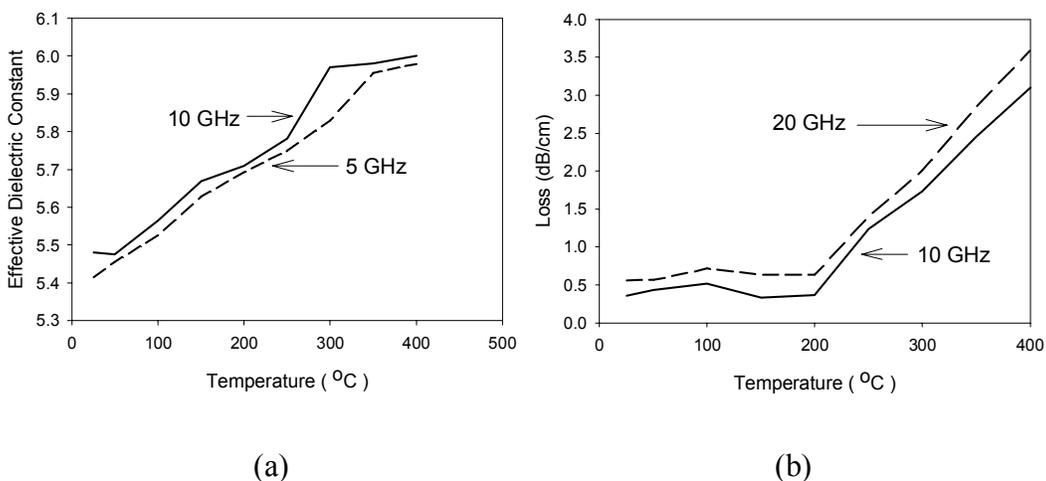


Figure 1.a) Effective dielectric vs. temperature at 5 and 10 GHz, b) Attenuation vs. temperature at 10 and 20 GHz.

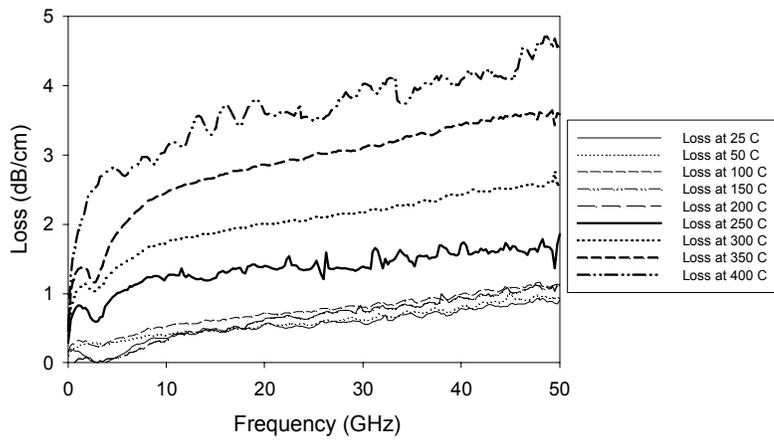


Figure 2. Loss vs. frequency as a function of temperature.

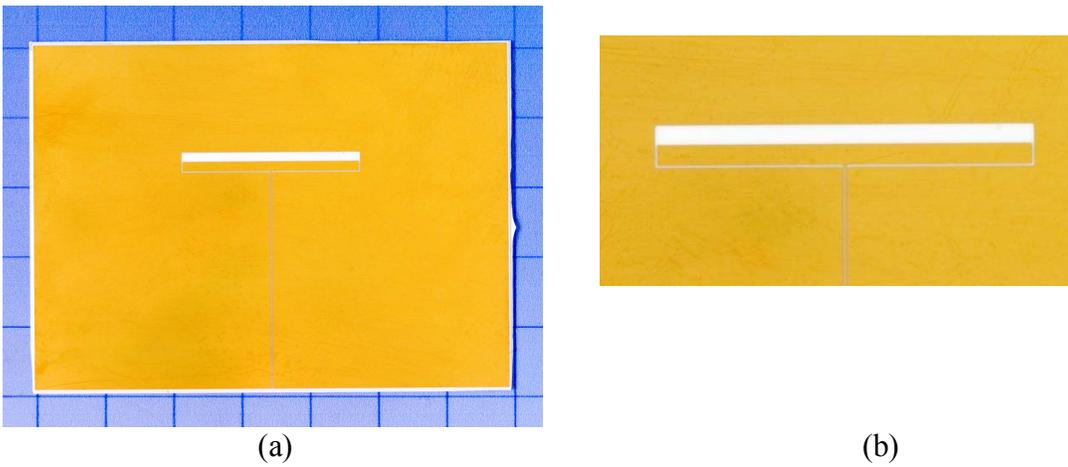


Figure 3. a) Folded slot antenna with CPW fed line b) Self impedance matching section.

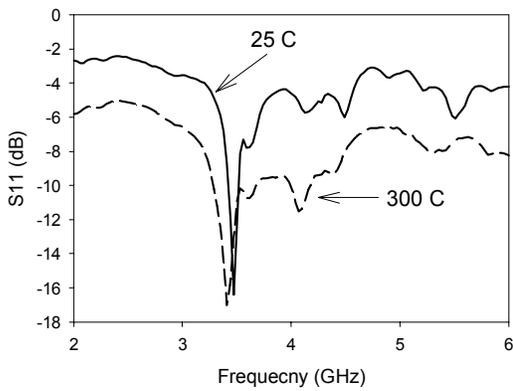


Figure 4. Return loss of folded slot antenna at 25 and 300°C.